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ABSTRACT

In considering the modification of weather, two obvious (but easily underemphasized) necessities are (1) to set forth clearly and completely the nature of the need that is being filled and (2) to align planning with forecasting. An illustration is given of situations in which augmentation of rainfall would and would not be prudent. Another illustration shows that actually controlling the weather would differ in utility from merely precipitating a larger fraction of water from clouds than nature would.

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INTRODUCTION

Over the past few years we have been attempting to assess cost--benefit ratios for weather information. In order to do this we found that two very important factors should be considered. First, the operator had to be able to take some action based on the information he received. It does somebody no good to know that there is going to be a large rainstorm if he can't protect himself from its damage or utilize its water. Second, we found that the best forecasts, or those forecasts which were right most often, were not necessarily those which were most economically useful. For example, if the cost of protecting is trivial compared to the cost of rain damage, clearly one can protect over and over again when the probability of rain is small in order to be secure when the one bad storm does come.

Let us compare the problems involved in weather modification and weather information. With weather information there is no material product, but in some cases in weather modification, there might be -- namely water. However, there must be some way of using the water when it is produced. Without the capability for using the water, there would be no point in producing more of it. A way in which they are similar is that the weather modification must be used in conjunction with forecasts in order to optimize the result. One would not deliberately try to make rain if there were going to be a natural flood. So we cannot ignore the need for good weather forecasting.

We have only begun to look at the economics of weather modification and to try to apply some of the lessons we learned in our previous study. There is still much to be done, but I will try to point out some of the factors which we have considered to date.

The economic gain of weather control can fall into two main categories. We can eliminate unfavorable conditions -- hail, lightning, severe storms. Or, we might actually produce something -- more sunshine, which would be perhaps better for certain kinds of growing crops, or the product which is of most interest here -- increased water supply. I will confine my remarks mostly to the information necessary for cost--benefit studies of increased rainfall.

COSTS

First of all, we must consider the cost. The costs here fall into three categories: initial research and planning, capital investment, and operating costs. I believe that we are now about to engage in a large-scale feasibility study to see whether or not rainfall can be produced in economic quantities in the Colorado River Basin. The decision has been made by the Congress to spend several millions of dollars for this research.

If it should turn out to be a feasible operation, we would then have to make additional capital investment and provide for the continued expense of operating the system and, more importantly, planning for the use and distribution of the water which we would hopefully add to the supply. I would like to point out that I think the cost of operation will be greater than simply throwing seeding material into the air. I hope to elaborate on this later in my talk.

VALUE

The value of additional water is a very, very difficult thing to estimate. Hirshleifer, DeHaven, and Milliman in their book on water supply point out that for the United States as a whole, we only make use of about 5% of the water which falls annually; 75% goes back into the atmosphere, and 20% of it goes back into the oceans without ever being put to any provident use. This is largely because of the unequal distribution of rainfall over the United States, but in part it is due to the fact that we do not have methods for efficiently using the water which we now have available. The question of the efficient use of water depends on how much we are willing to pay to get it. Now, I do not propose to go into a long economic analysis of the value of water. If it were strictly an economic problem, a good case could be made that there is no water shortage. All we have to do is pay for it. But there are other ethical and legal factors which govern the use of water. We have a

sort of self-deception -- namely, that we think of water as something which should be free, should be available to all, but unfortunately, in many parts of our country, it isn't. I trust that the following speaker will have something to say about the legal aspect of water distribution.

In a recent publication entitled, Aridity and Man, Wilson has made a study of the Tucson problem of the uses of water, and the projections that were made for Tucson were that each acre foot of water for agricultural purposes added value to the community at the rate of about $210. Each acre foot used in mining operations added in value to the community about $3700 and in manufacturing added about $3200.

In that same book, another estimate for an arid area's use of water, by Gurnsey and Wollman, indicated that irrigation water added about $17 per acre foot, mining and manufacturing together added about $1200 and that the recreational use of water added about $300. I hold no brief for any of these estimates. I simply want to point out that the value of an acre foot of water is strongly dependent on how and where it is used, and that there is not much point in trying to estimate precise values unless the use to which the water is to be put is well known.

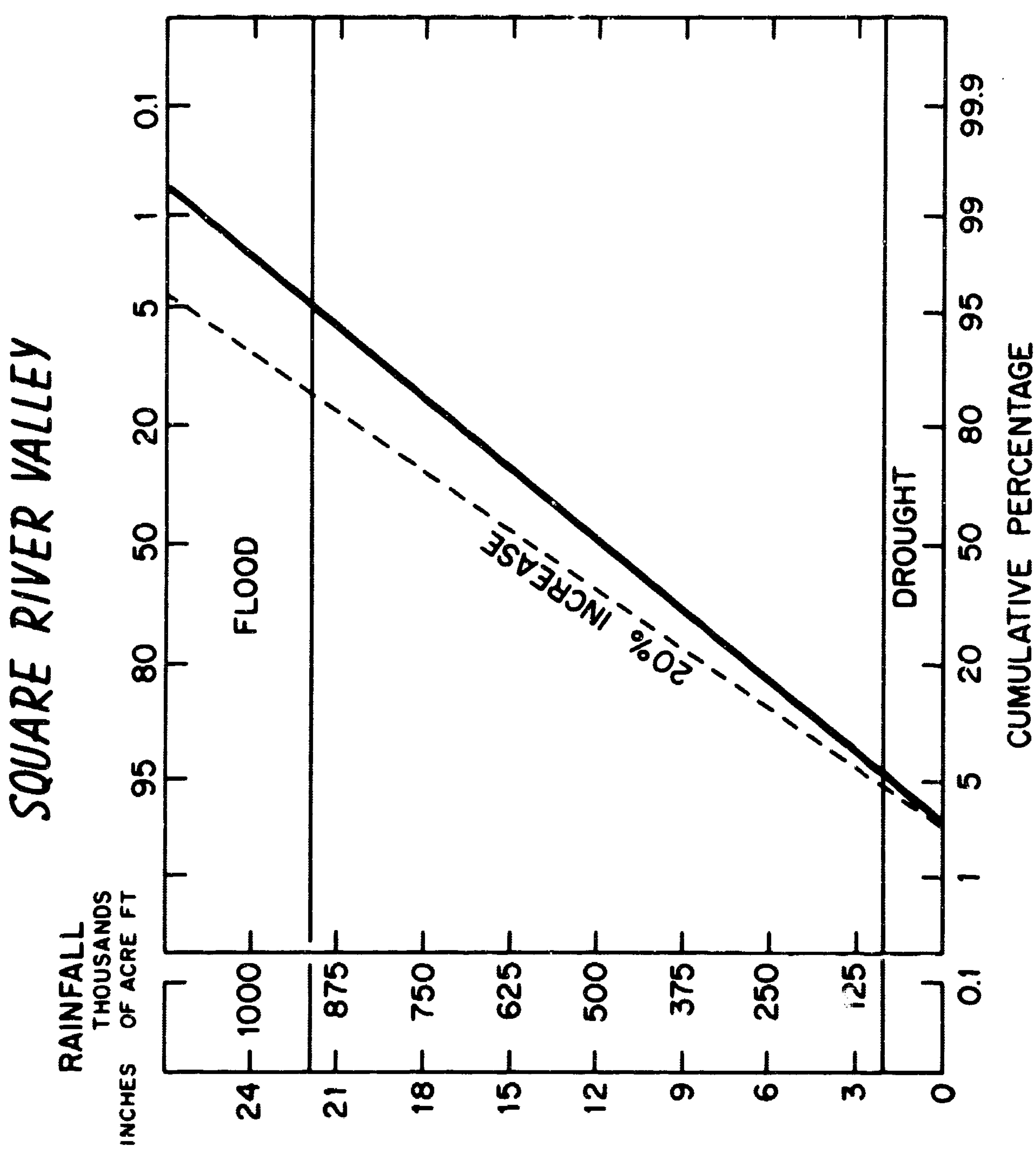
We should perhaps consider possible economic losses incurred in a rainfall-augmentation project. The possibility that the production of additional rainfall in one part of the country would reduce the rainfall in another part of the country always exists, and I will have more to say about weather modification rather than rainfall augmentation a little bit later. Another probable loss is that people with different desires in the way of weather might be operating in the same area. Thus farmers might long for rain, but resort operators might want clear weather. This now becomes a topic for the next speaker on the legal aspects of weather modification.

THE SQUARE RIVER VALLEY

I would like to make a distinction between weather modification and rainfall augmentation. But I should like to talk first about the effect of increasing the rainfall. In order to illustrate some of the economic effects of a rainfall-augmentation program I have invented a river basin which I call the Square River Valley, and I have invented some plausible, but not necessarily real, water problems for this valley. This is to be illustrative only, but I hope it will bring out some of the difficulties that might face a rainfall-augmentation program.

Consider the Square River Basin, approximately forty miles on each side and containing exactly one million acres. It is a western valley which is rather well watered by winter storms and has an annual average rainfall of 24 inches. It is a place which over the last half century has adapted fairly well to the climate; its economics are well adjusted and its water-management policies are relatively stable. Despite its adjustments, the natural variations in the weather from year to year are some cause for concern; it would be nice if they were eliminated. These natural variations are caused by the fluctuation in number and intensity of the winter storms which supply the water. They are brought about in large measure by the large-scale variations in the weather pattern.

The heavy black line in Slide 1 represents the distribution of the average annual amount of precipitation over the basin. The abscissa is the cumulative probability of getting as much precipitation as is shown on the ordinate. For example, 70 per cent of all years will have less than 30 inches of precipitation. The scale at the top is simply the inverse; using the same point we can read that 30 per cent of all years will have more than 30 inches of rainfall. The inner figures of the ordinate represent the number of acre feet of water available for provident use. The assumption has been made that, for this river valley, 1/4 of the rainfall is incorporated into the water system; the other 3/4 is lost through evapotranspiration.


SQUARE RIVER VALLEY
RAINFALL
INCHES
THOUSANDS OF ACRE FT
24
21
18
15
12
9
6
3
0
1000
875
750
625
500
375
250
125
0.1
95
80
50
20
5
1
0.1
FLOOD
20% INCREASE
DROUGHT
99.9
99
95
80
50
20
5
1
CUMULATIVE PERCENTAGE

Slide 1

On the top of Slide 1 there is an area labeled flood. This was arbitrarily set at the 95 per cent level which amounts to one year in twenty. I do not mean to imply by the word "flood," a catastrophic occurrence, but rather that the water in excess of this amount cannot be retained by reservoirs and flood control dams, and cannot find its way into the aquifers which support the wells. It is water which cannot be put to any provident use because of lack of storage capacity. In the same manner, the lowest five per cent of the years is labeled drought. This is likely to be a much more serious problem and one which calls to mind the hope of additional water from modification experiments. If the assumption that this river basin has adapted to the climate is to be reasonable, it is also necessary to make the assumption that subsurface storage of water will tide the populace over some of the dry years. The drought line, therefore, indicates that degree of dryness that cannot profitably be compensated for by the use of additional well water.

The dashed line on the slide represents a possible additional supply of water from rainfall-augmentation practices. It is a constant 20 per cent added to the natural rainfall. The 20 per cent figure was chosen for two reasons: First, most of the studies of weather modification report their results in terms of percentage increase, and this figure is a sort of average of the most optimistic reports. Second, the water vapor in the air which is available to be precipitated, varies with the large-scale circulation, and the natural precipitation is a crude measure of the availability of water. You may note that this across-the-board increase of 20 per cent increases the frequency of flood conditions to 16 per cent from 5 per cent, but only decreases the incidence of drought from 5 per cent to 4.5 per cent.

Assuming that the water system, both man-made and natural, can conserve up to about 43 inches of precipitation annually, some of the additional water produced by the modification techniques could be retained for use in the dry years, but this could not be done with perfect efficiency. Furthermore, precipitation in excess of 50 inches represents a really large flood, the once-every-100-year

variety. One would therefore try to limit the modification in years when there were indications of high natural rainfall. I would estimate that a wisely run modification program which had the potential of increasing the yearly annual precipitation by 20 per cent would, in the long run, add between 10 and 15 per cent to the productive water supply of the valley. The use of modification procedures only when the natural rainfall is near the drought condition would tend to be quite disappointing, producing 10 to 20,000 acre feet, where as the deficit is near 100 to 200,000 acre feet.

I think there are three main points to be considered from this hypothetical analysis: First, a rainfall-augmentation program will not be very helpful in those years when it is normally dry. A small increment of water could be added, but it will be very much less than that which is needed.

The second point is that the rainfall-augmentation projects must be coupled with some understanding of the weather processes, and adequate forecasting. One has to know something about the current water supply and the possible future rainfall in order to know if one should try to induce more precipitation, or leave nature to its own devices.

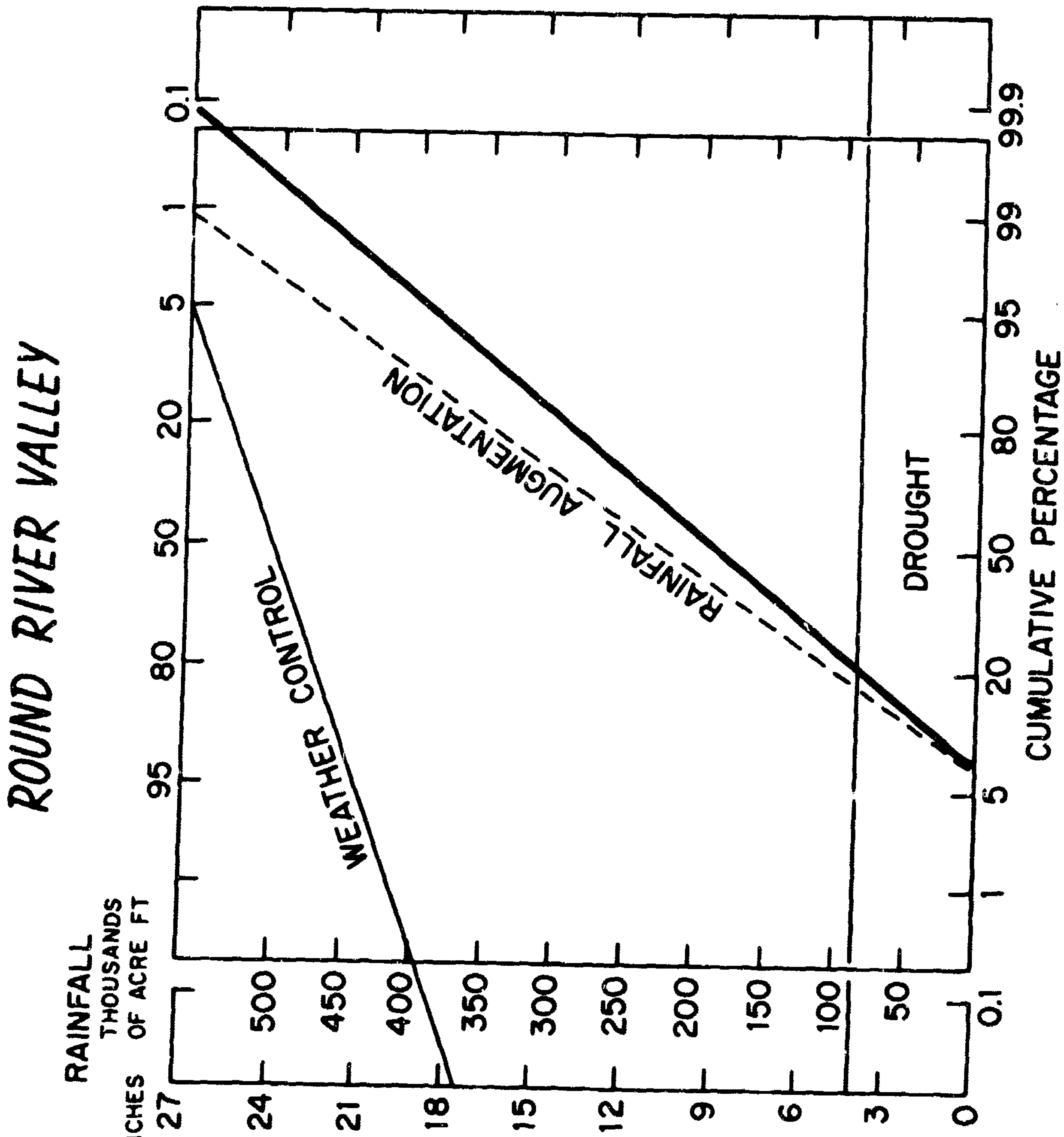
The third point is that the rainfall-augmentation will be used in exactly the same way that the natural precipitation is used. In other words, there must be storage and distribution facilities. The additional water will require the development of additional storage. The added rainfall will not be free, nor will its cost be only that of running the augmentation program. The water will be added to the normal supply, and the cost of distribution and pumping will still apply to this added rainfall. I believe that in some marginal areas where efficient use is being made currently of the natural precipitation, a rainfall-augmentation program might be profitable. However, one must be prepared to utilize any additional water which is produced, and one must be prepared to operate the rainfall-enhancement program efficiently.

WEATHER MODIFICATION

I should now like to spend a minute or two on the possibilities of a weather-modification program -- not just rainfall increase. There exists a possibility that if we know more about the natural behavior of the atmosphere, we can interfere in much more fundamental ways. I made the point earlier that a rainfall-augmentation program is dependent on the amount of moisture which crosses the river valley and is available to be precipitated. Ideally, we would like to be able to control the amount of water vapor in the atmosphere which crosses this river valley. We would like to be able to smooth out the variation in the curve to induce more clouds and more water vapor in the dry years, and to cut down on the amount of precipitation in the very wet years. Such control of the weather is probably a long way in the future. We as yet do not understand how and why the atmosphere behaves. But the tools are available to begin to study the problem of weather control. The large-scale computer models of the atmosphere provide us with the means for trying out ideas without endangering our present balance of climate.

THE ROUND RIVER VALLEY

Turn now to another invented basin which I call the Round River Valley. This is the same size as the previous example, 1,000,000 acres, but has a different rainfall regime. It is a typical desert situation with a smaller normal annual rainfall, 9 inches, and a relatively greater range of annual rainfall. The bulk of the precipitation in this type of valley comes from summer convective showers. Slide 2 shows the distribution of annual rainfall amounts on the same type of graph as Slide 1. If we apply the drought criterion which has the same number of acre feet of available water as the previous example, we note that drought would occur about 20 per cent of the time, or 1 year in five. I think it is safe to assume that such a place would be given over to grazing and not have much of a managed water supply. If the same percentage increase is


ROUND RIVER VALLEY
RAINFALL
INCHES
THOUSANDS OF ACRE FT
27
24
21
18
15
12
9
6
3
0
500
450
400
350
300
250
200
150
100
50
0.1
1
5
20
50
80
95
99
99.9
0.1
WEATHER CONTROL
RAINFALL AUGMENTATION
DROUGHT
CUMULATIVE PERCENTAGE

Slide 2

applied to this valley, the years of drought could be reduced to 1 year in six -- hardly an economically useful change. It is almost unnecessary to point out that seeding experiments on the summer convective storms in the desert regions have not been as optimistic as the experiments on winter storms. The point I am trying to make with this example is that the rainfall-augmentation techniques which we now believe might increase the natural rainfall by a reasonable fraction, will not be sufficient to make a presently desert valley into a productive one.

If, however, a true weather-modification project could be managed which would produce a distribution such as the one labelled "weather control," on the diagram, the valley could really be brought into useful production.

CONCLUSION

The job will be expensive. We must support a great deal of basic research for which the immediate value cannot be projected. However, if the probability of success in weather-control programs is very, very small, but the possible increased value is very, very great, it becomes economically reasonable to risk the money required to study the problem.

If we were able to find out how to induce a greater supply of water into the Round River Valley, it might be extremely valuable in the production of food or perhaps even the establishment of manufacturing. If we could eliminate the variation of rainfall -- cut out the drought years and the flood years in the Square River Valley -- this would provide us with a much more economical method for operating a water system. Even if the possibility of this kind of true weather control is very small, the values which might be realized if it were obtained are certainly worth some investment in research along these lines.

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